

Sensitivity of ATLAS to Extra Dimensions

Nick Brett
University of Oxford

Large Extra Dimensions

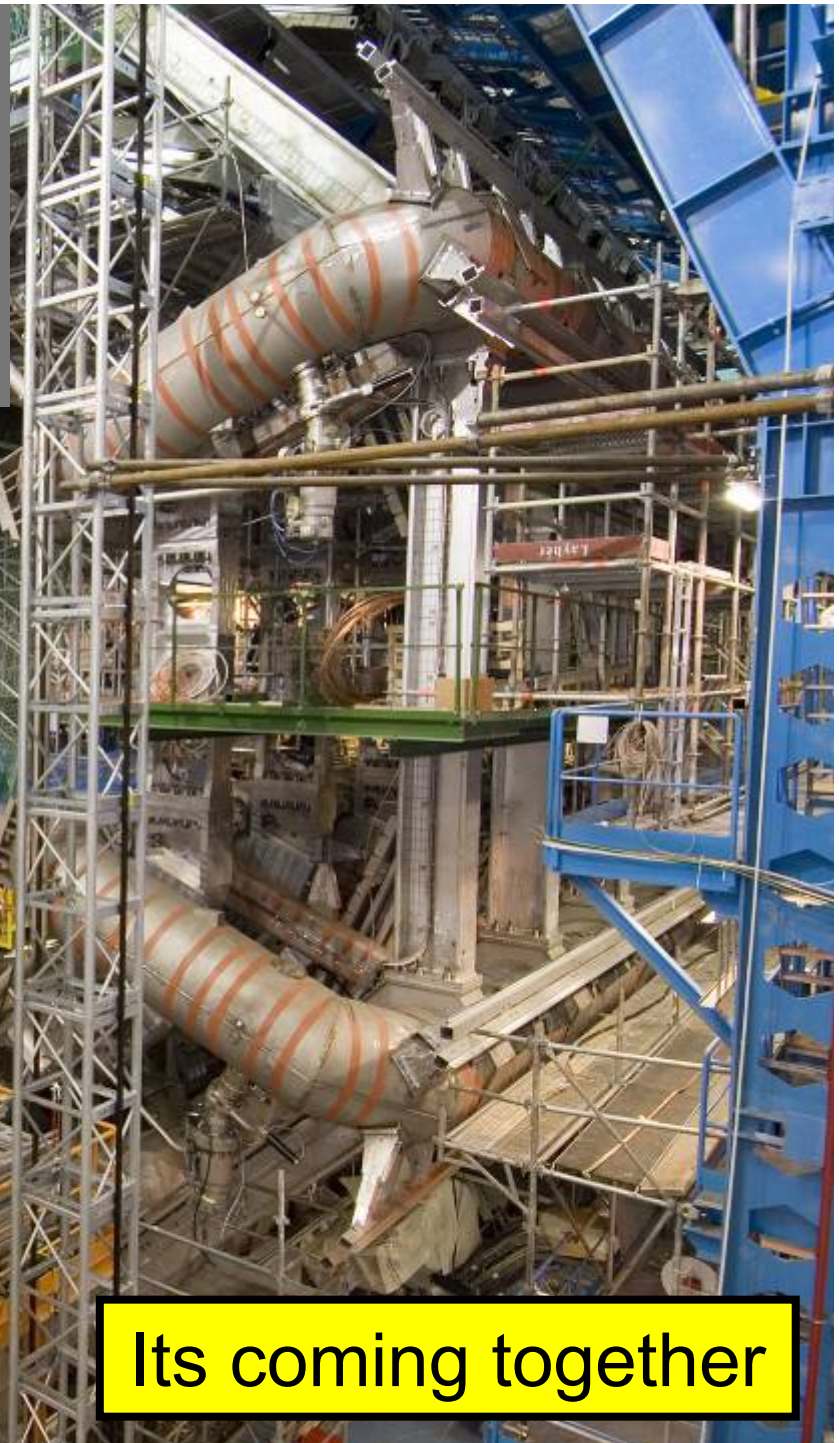
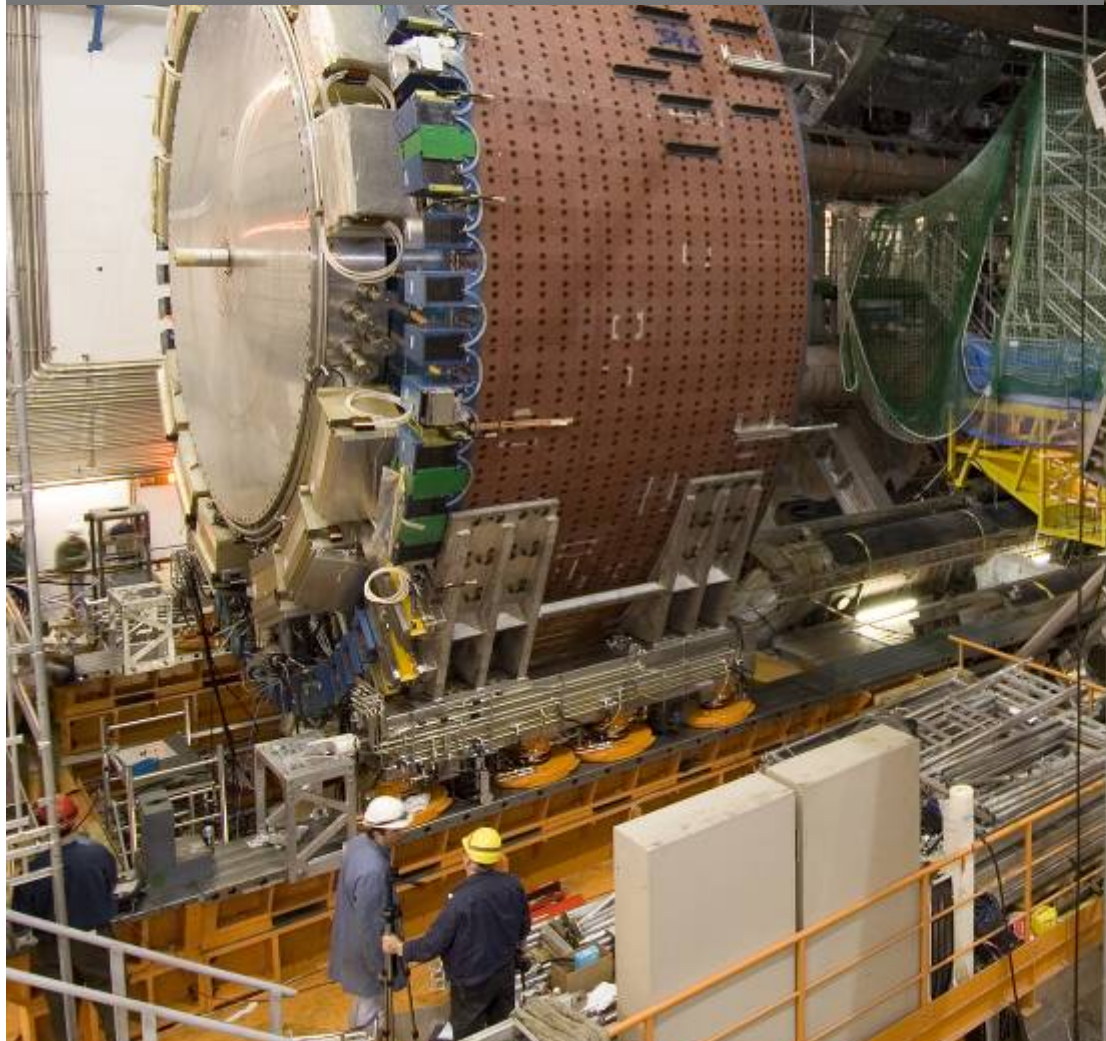
Warped Extra Dimensions

Universal Extra Dimensions

Micro Black Holes

Physics at LHC 3-8 July 2006

ATLAS



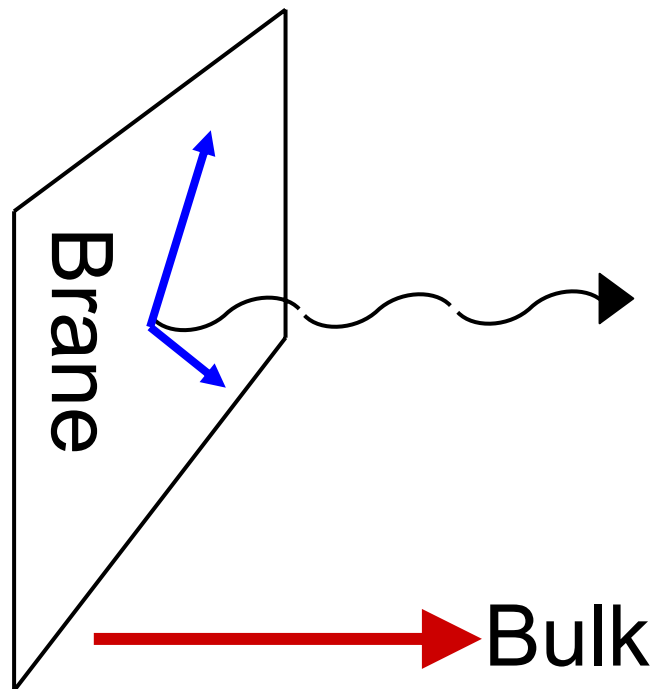
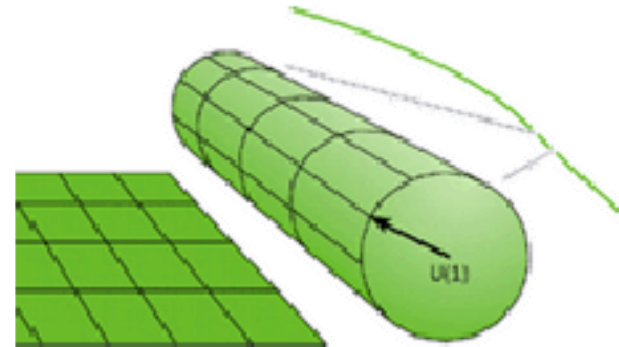
Its coming together



Extra Dimensions

Not a new idea (1920's)

Kaluza and Klein tried to unify
Electro-magnetism and General
Relativity



Undergoing a Revival

Access to Extra Dimensions can be restricted

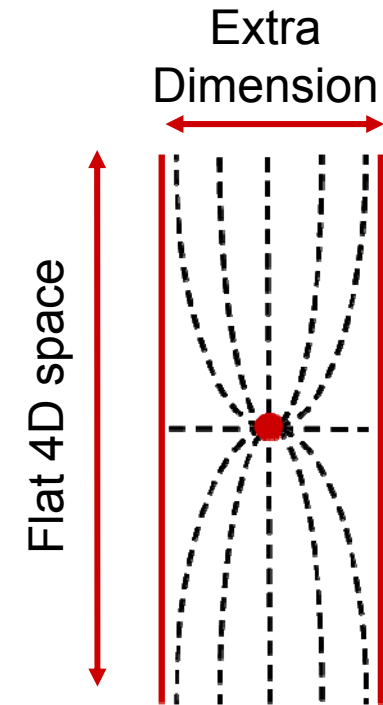
- Can Solve Hierarchy problem
 - M_{pl} is only an effective scale
 - New fundamental scale M_f
- Essential for String Theory
- Can be compactified



Large Extra Dimensions

ADD

- Extra Dimensions are **flat**
- Only accessible to **Gravity**
- SM particles restricted to **4D Brane**
- Could be as **large** as 0.1mm



Generates Tower of **KK gravitons**

- Coupling proportional to $1/M_{\text{pl}}$
- Mass splitting $\sim 1/R$
- Observe a continuum of graviton states

Extra dimensional momentum
looks like a mass

$$E^2 = P^2 + m^2$$
$$= P_x^2 + P_n^2$$

Large Extra Dimensions

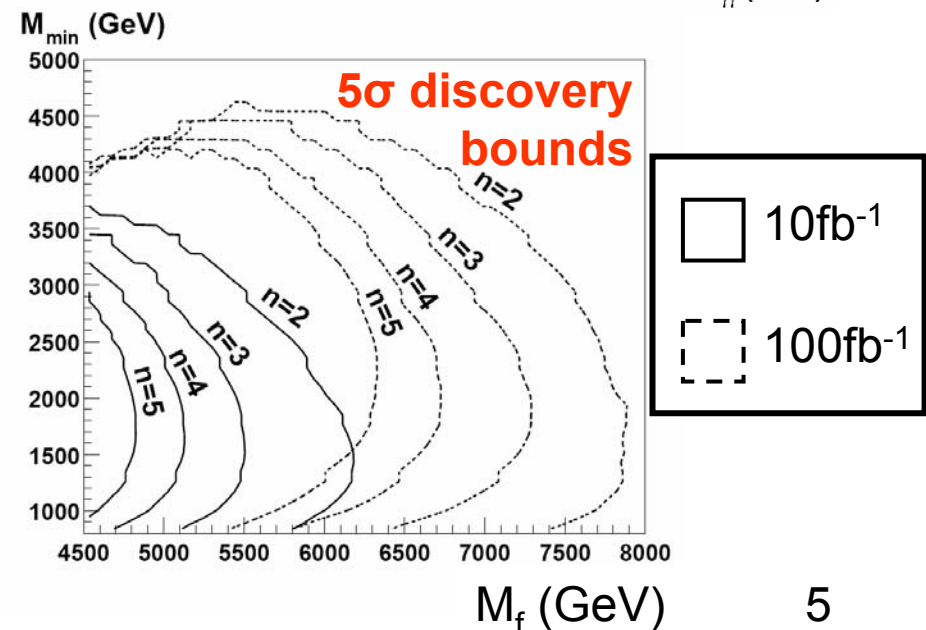
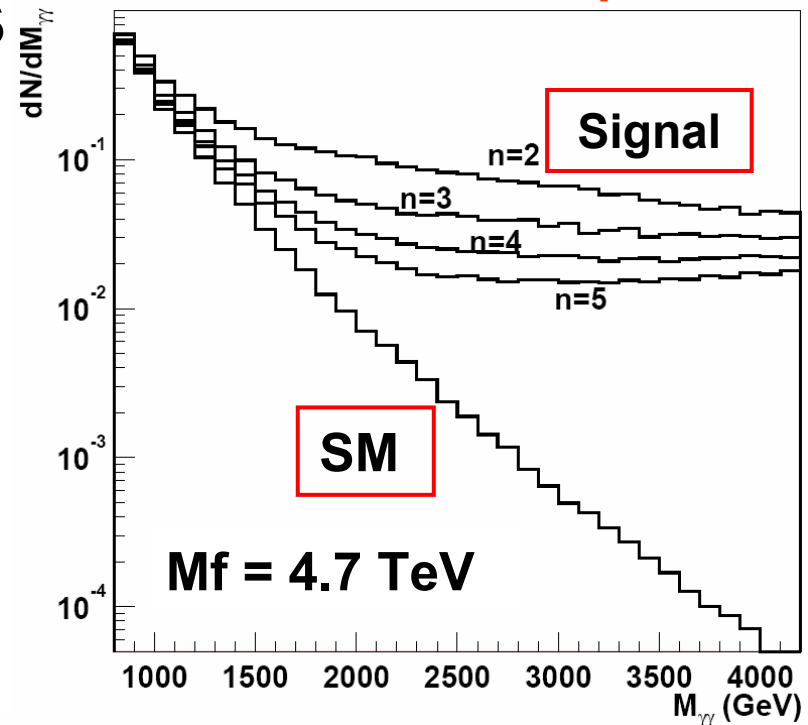
Di-photon/lepton

Kabachenko, Miagkov, Zenin
[ATL-PHYS-2001-012]

- virtual graviton exchange
- Tower of KK gravitons
- Measure invariant mass of photon/lepton pair
 - Min invariant mass cut extends reach

Sensitivity @ 100fb^{-1}
 5σ for M_f 6.3-7.9 TeV

Enhancement of di-photon



Warped Extra Dimensions



Randall Sundrum (type I)

Randall, Sundrum

[PRL 83 (1999) 3370]

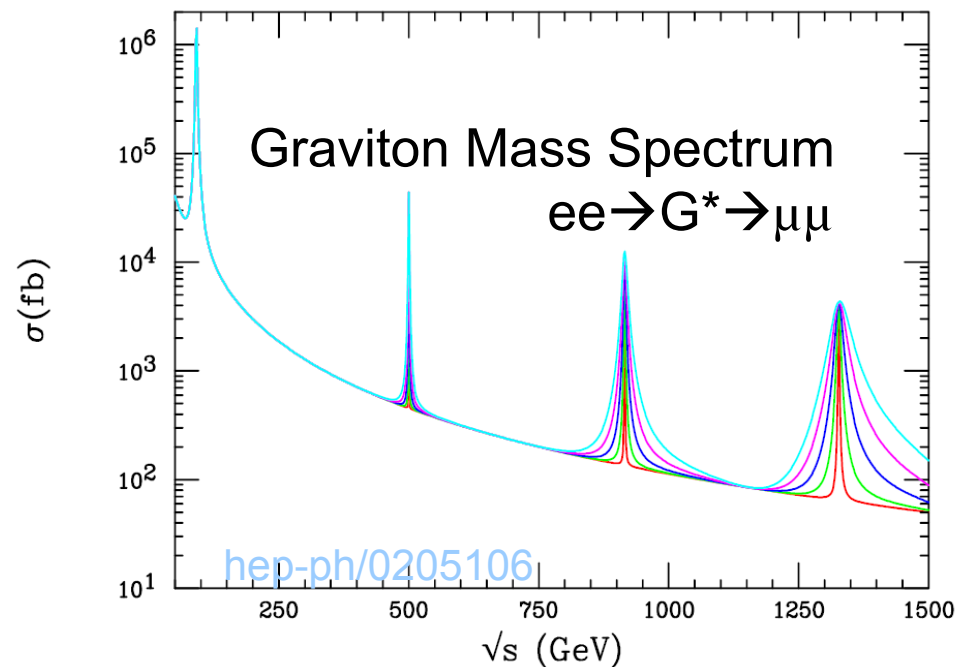
- Brane metric scales as function of **bulk position**
- Solves Hierarchy problem using **warp factor**
- **Small** extra space dimensions
- Well **separated** graviton mass spectrum

Characterized by

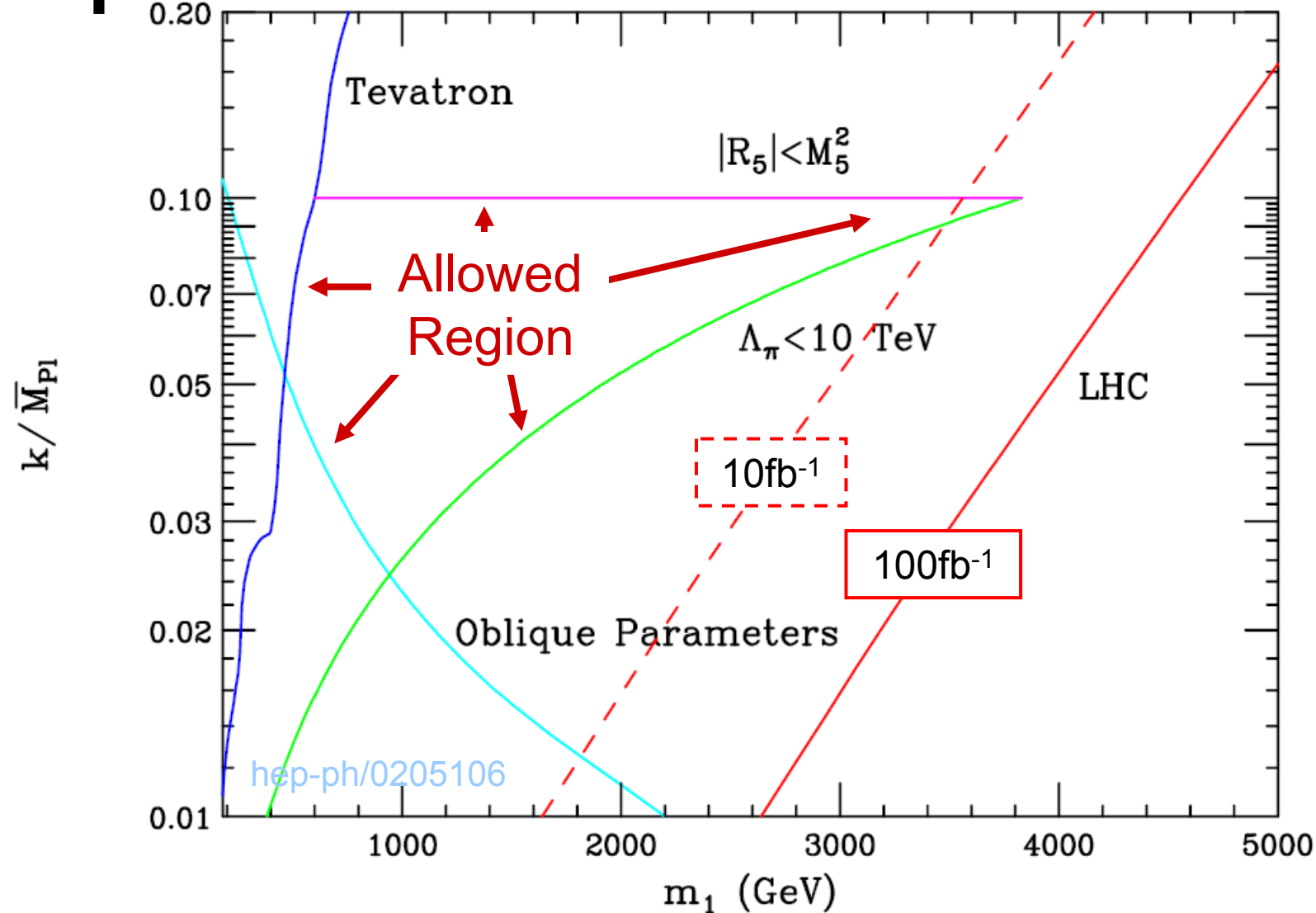
$$k/\overline{M}_{pl}$$

Nick Brett – University of Oxford

$$ds^2 = e^{-2ky} \eta_{uv} dx^u dx^v - dy^2$$



Warped Extra Dimensions



ATLAS is able to explore the entire allowed region

Warped Extra Dimensions



$$G^* \rightarrow e^+ e^-$$

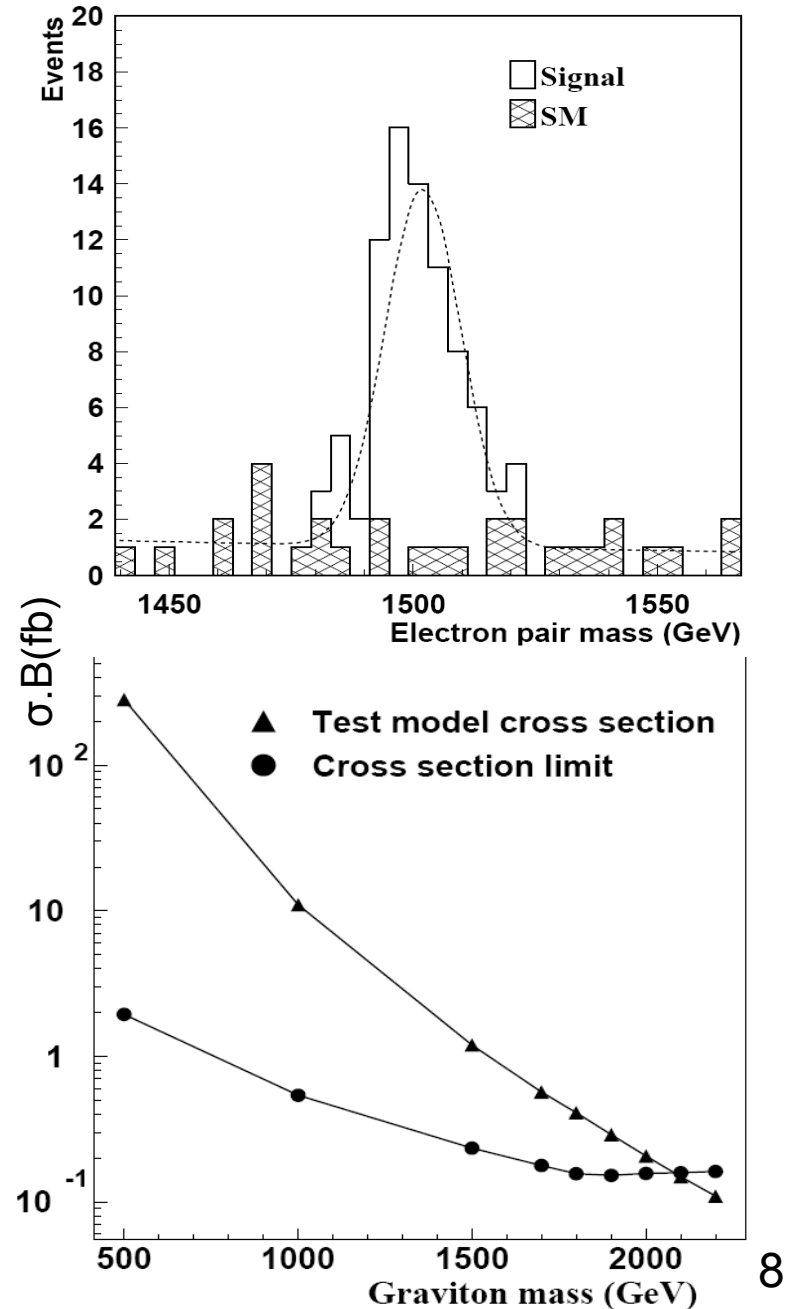
*Allanach, Odagiri, Palmer,
Parker Sabetfakhri, Webber*

[JHEP09(2000)019]

[JHEP12(2002) 039]

- Graviton
 - Produced in kk spectrum
 - Looked for 1st KK mode
 - Studied models with narrow resonance

**Sensitivity @ 100fb^{-1}
 5σ up to M_G 2.08TeV**



Universal Extra Dimensions



Beauchemin, Azuelos

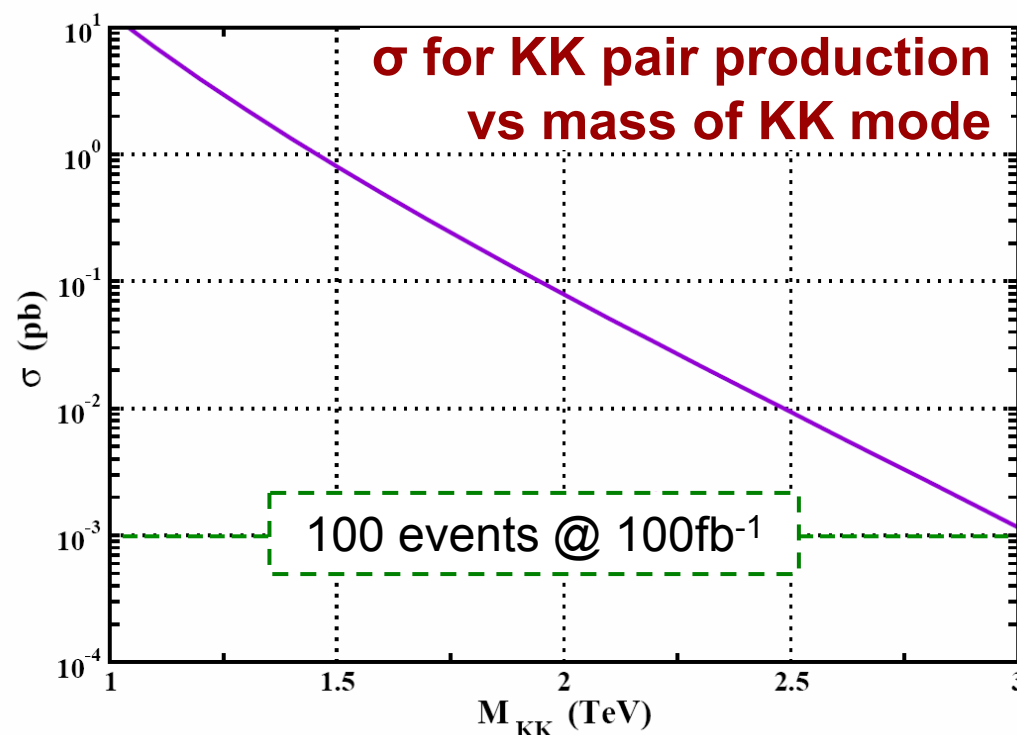
[ATL-PHYS-PUB-2005-03]

SM particles propagate in Extra Dimensions

- can move in **small** Extra dimensions
- Often **embedded** in large Extra Dimensions

KK parity

- similar effect to R-Parity
- conserved at Tree level
- KK particles always in pairs
- no virtual KK particles



KK parity conservation
means limits on UED are
much weaker

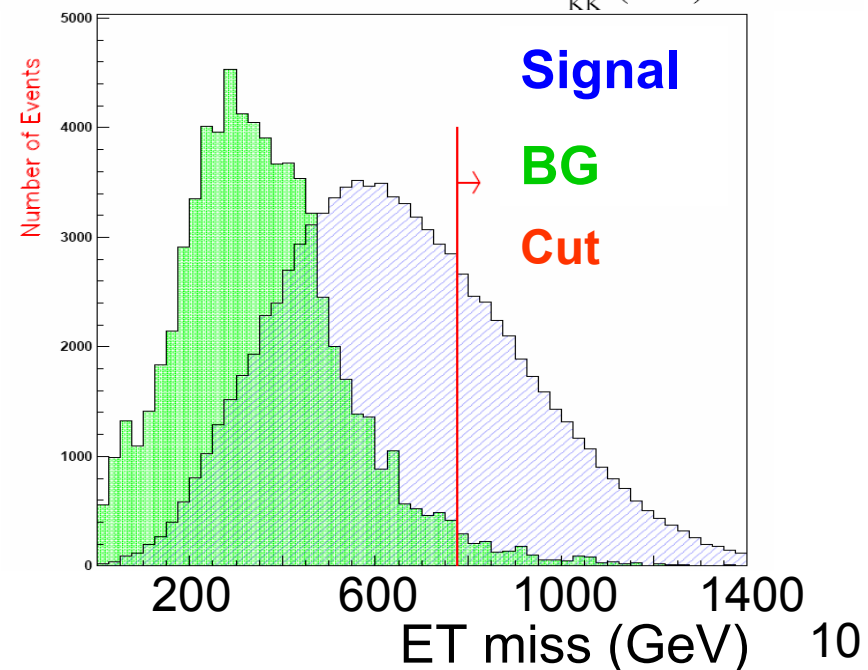
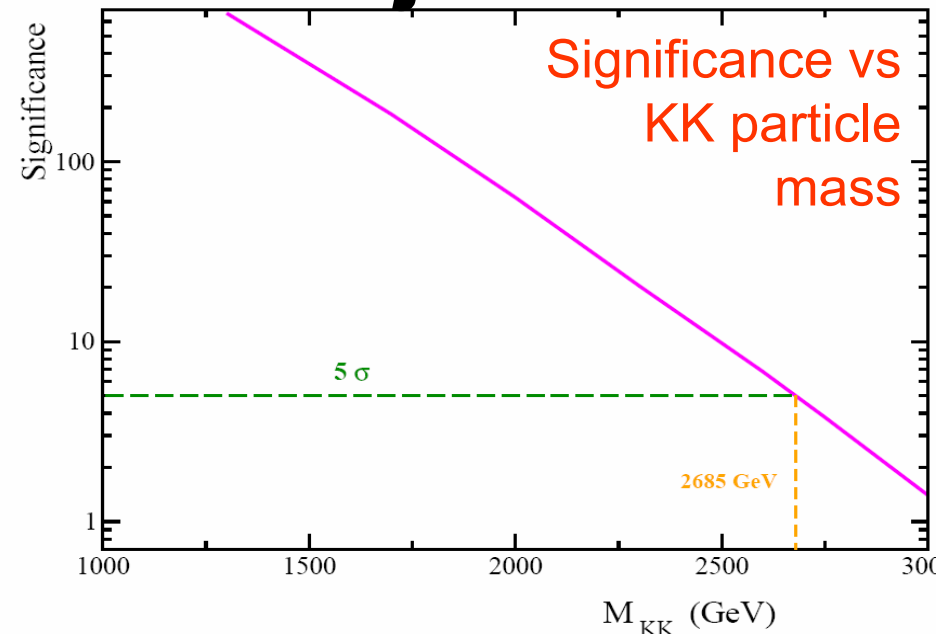
UED: KK quark/gluon \rightarrow di-jet



*Beauchemin, Azuelos
[ATL-PHYS-PUB-2005-03]*

- Direct KK mode production only
- Measure excess of dijets with large missing E_T
- Assume all KK modes decay to gravitons (invisible)

**Sensitivity @ 100 fb⁻¹
5 σ up to 2.7 TeV**



UED: KK gluons \rightarrow Heavy quarks



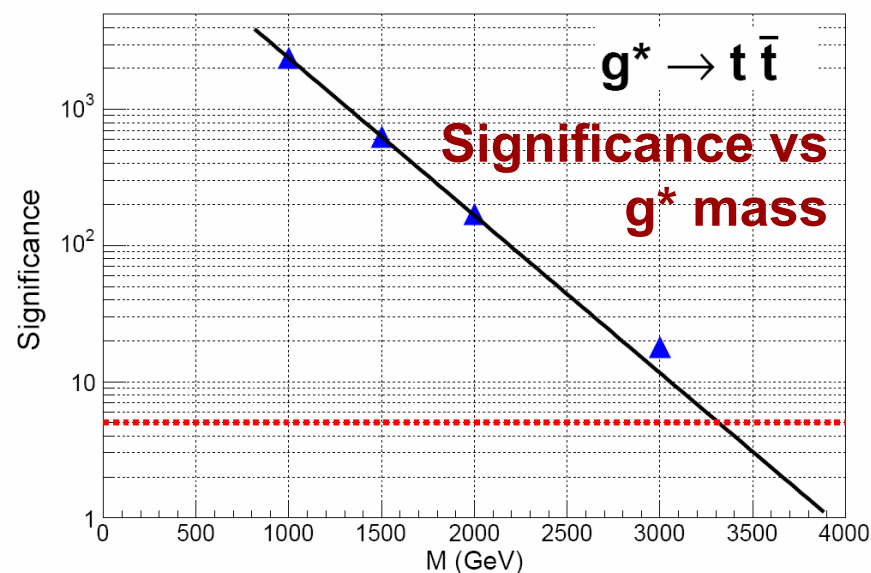
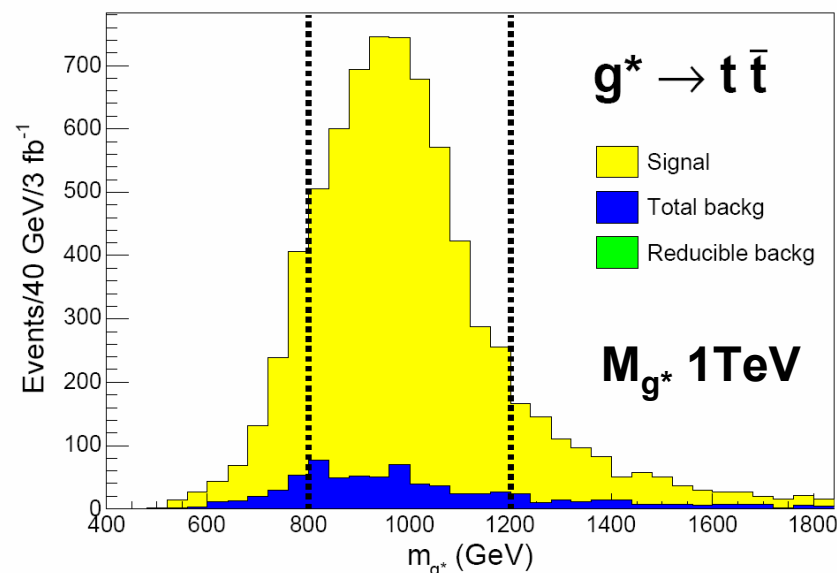
$$g^* \rightarrow bb/tt$$

March, Ros, Salvachua

[ATL-PHYS-PUB-2006-002]

- Only produce hadronic decays
- Tag Heavy quark decays
- Excess of di-jets
- b-quark decays difficult to detect
- t-quark channel provides clearest signal

**Sensitivity @ 100fb⁻¹
5 σ M_{g^*} up to 3.3TeV**



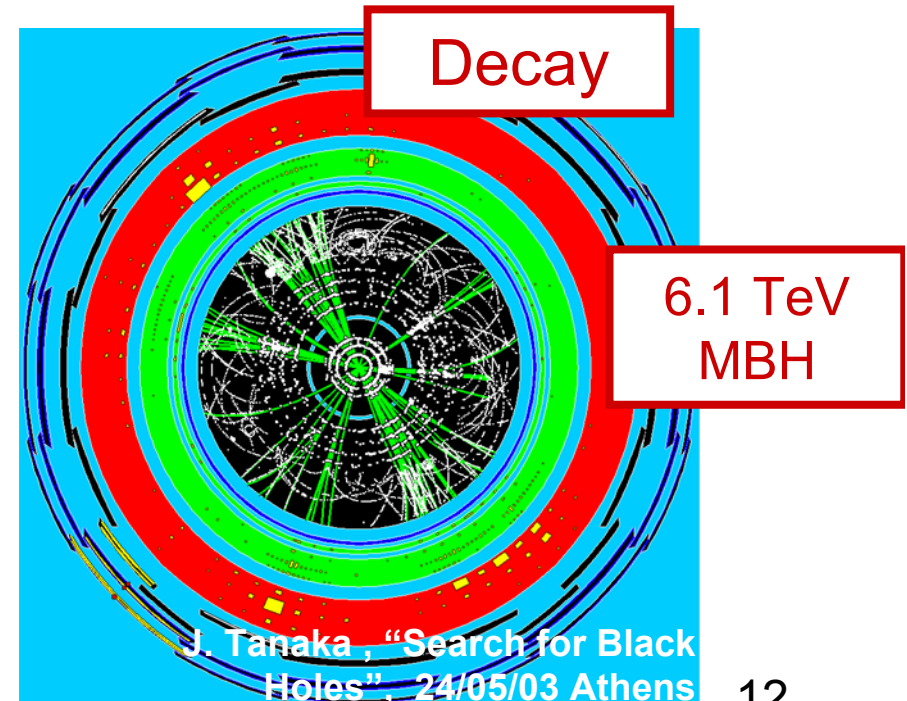
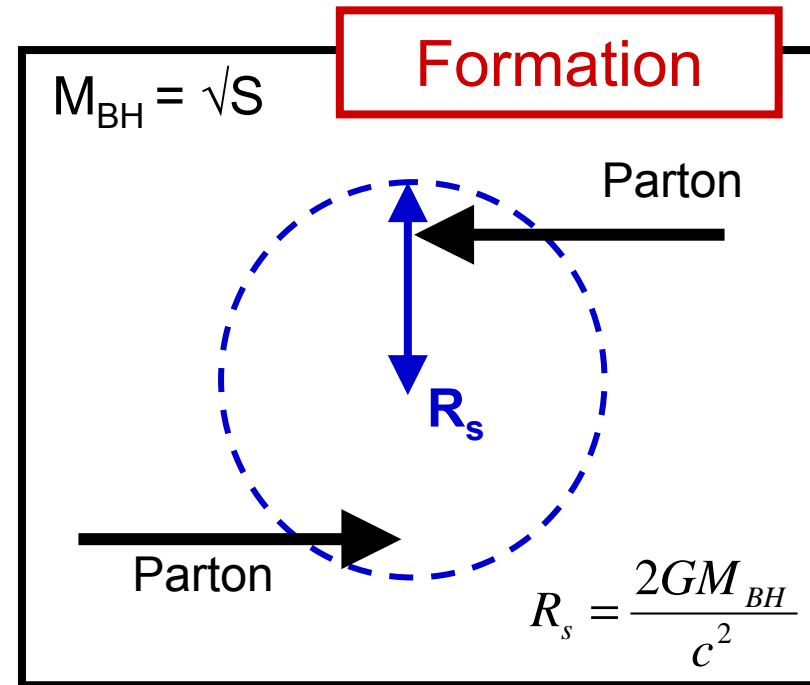
Micro Black Holes

*Harris, Palmer, Parker,
Richardson, Sabetfakhri, Webber
[JHEP05 (2005) 053]*

- $\sigma \sim \pi R_s^2 \sim O(100)\text{pb}$
- LHC \rightarrow Black Hole Factory
- BH lifetime $\sim 10^{-27} - 10^{-25}$ seconds!
- Decays with equal probability to all particles via Hawking Radiation
- Follows almost black body spectrum

$$T_H = \frac{1+n}{4\pi R_{BH}} \approx \frac{1+n}{M_{BH}^{1/(1+n)}}$$

Nick Brett – University of Oxford





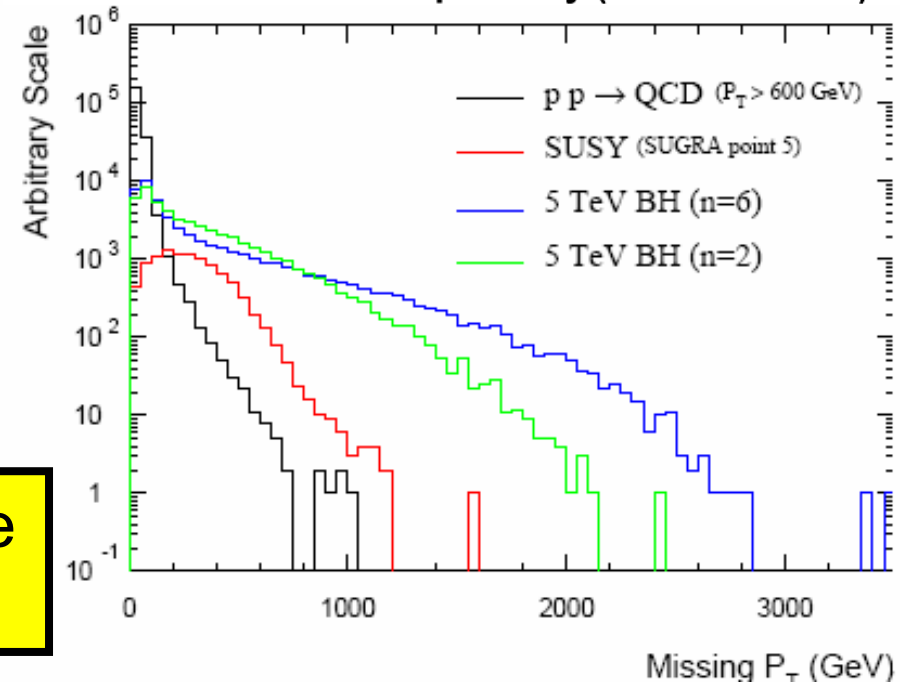
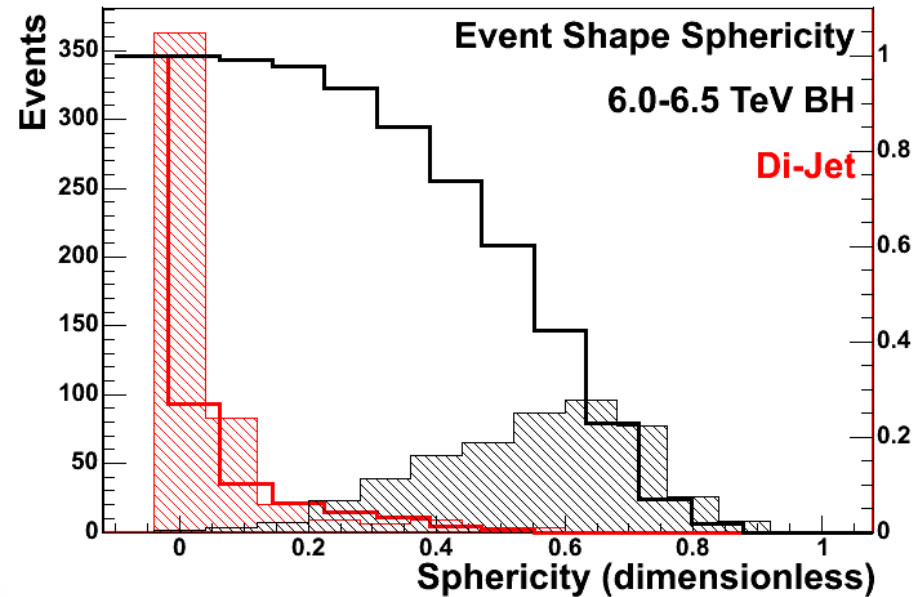
Micro Black Holes

Distinguishing features

- High Multiplicity
- High ΣE_T
- High Sphericity
- High Missing P_T
- Democratic Decay

Sensitivity Dominated by Theoretical uncertainty

If $M_{pl} \sim O(1 \text{ TeV}) \rightarrow$ Black Hole Production possible at LHC



Summary



5σ discoveries with $100fb^{-1}$

- ADD fundamental M_{pl} up to 7-8 TeV
- RS graviton up to 2.08 TeV
- UED KK particles up to ~ 3 TeV
- If Micro Black Holes are produced we will know!



Backup Slides

Large Extra Dimensions



Jet + E_T miss

- Direct graviton production

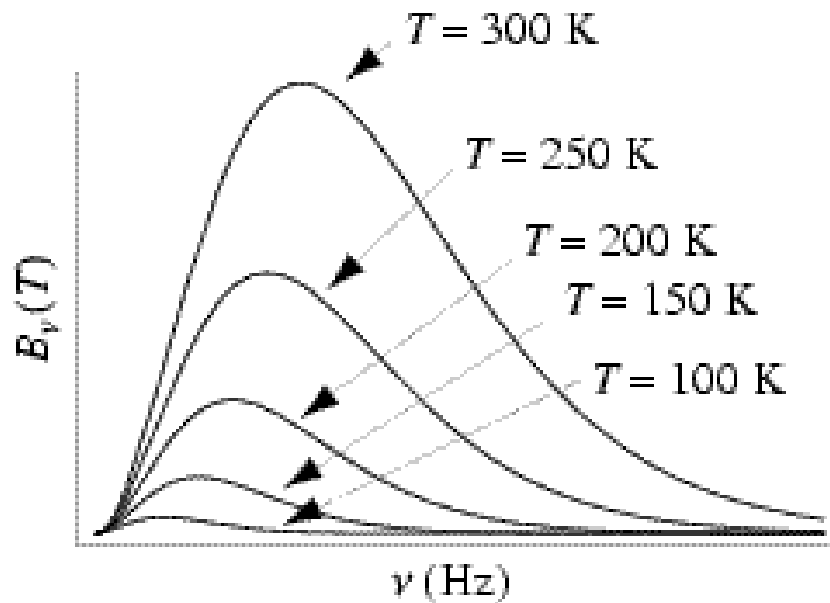
Vacavant, Hinchliffe

[JPG 27(2001) 1839]



Black Hole Decay

- Decay via Hawking Radiation
- Emit particles following an approximately black body thermal spectrum



$$T_H = \frac{1+n}{4\pi \cdot R_{BH}} \approx \frac{1+n}{M_{BH}^{1/(1+n)}}$$

n = number of extra dimensions

- Spectrum modified by Grey Body factors
 - Black Hole might not maintain Thermal equilibrium
-
- Astrological BH -- **COLD** -- Low Evaporation
 - Micro BH -- **HOT** -- High Evaporation



Black Hole Events in ATLAS

BH evaporates into

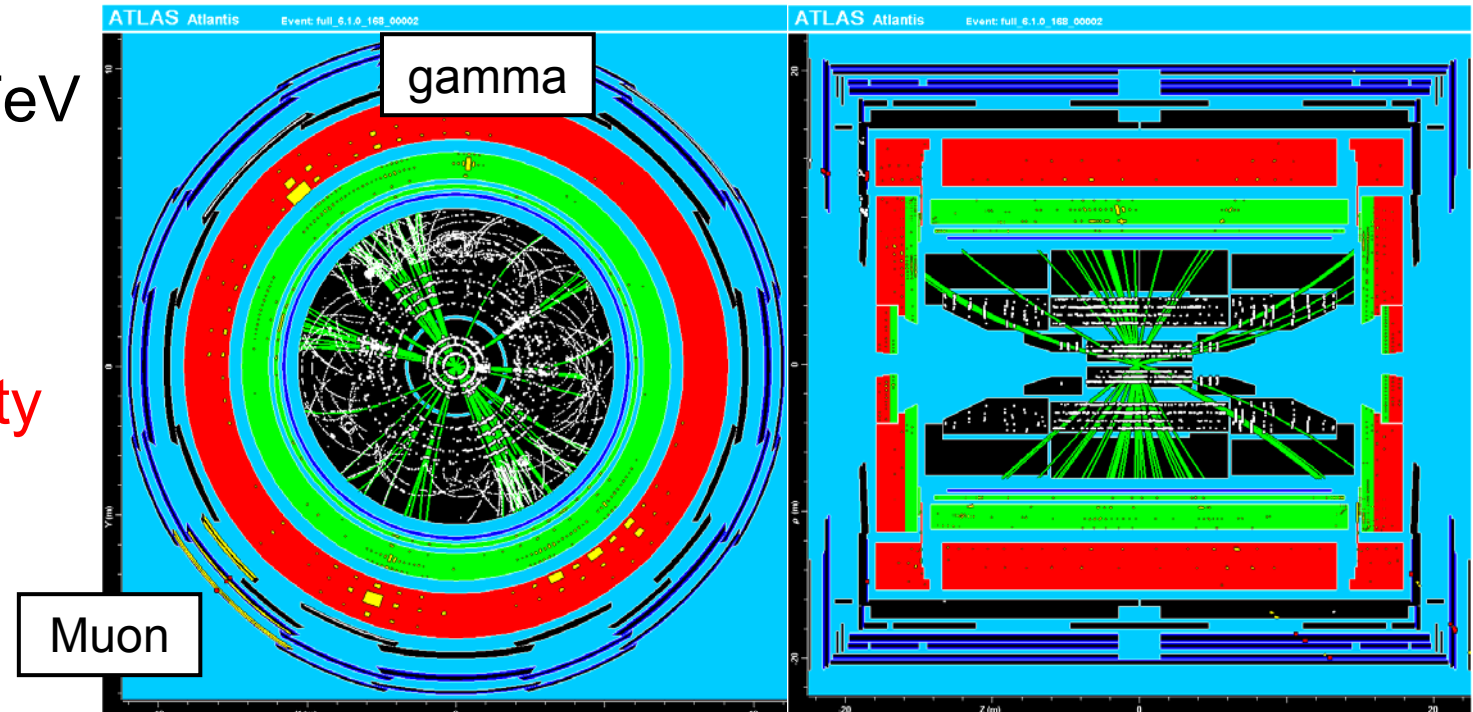
(q and g : leptons : Z and W : ν and G : H) = (72%:11%:8%:6%:2%:1%)

(hadron : lepton) is (5 : 1) accounting for t, W, Z and H decays

S.B. Giddings, S. Thomas, [Phys.Rev.D65(2002)056010]

Decay of 6.1 TeV
Black Hole

High multiplicity
events



J. Tanaka, "Search for Black Holes", 24th May 2003 at Athens